Prepared for International Conference on High Intensity Magnetic Fields, Cambridge, Mass, Nov. 1-3, 1961

Goddard

E-1505

THE NASA HOMOPOLAR GENERATOR AS AN ELECTROMAGNET POWER SUPPLY

by John C. Fakan

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

INTRODUCTION

Early in the magnetics research program at the Lewis Research Center a decision had to be made as to the type and scope of power supplies to be used for driving contemplated electromagnets. The biggest concern, by far, was that of the impedance, or voltage to current ratio, of the power supply.

After a careful study of the proposed aims of the research program, it was decided that very low impedance systems had the most to offer.

Some of the arguments used in reaching this decision were as follows:

(1) The inherent self strength of large-cross-section conductors would help to eliminate the need for supporting structures within the magnet and the resulting decrease in magnet efficiency.

(2) City water could be used directly as a coolant, since low-impedance electromagnets have small turn-to-turn potential differences and thus have no need for special coolants or insulation techniques to avoid electrolytic erosion problems.

(3) Since cryogenically cooled magnets were also contemplated, the resulting very low conductor resistances would require a high current (low impedance) power source.

As can be expected, there were also some arguments against this choice, such as:

(1) The conductors which couple the magnets to the power supply would have to be of large cross section.

(2) The construction of room-temperature water-cooled magnets might be difficult because of the large conductors required.

It was felt, however, that the potential advantages outweighed the possible problems.

The power level desired was in the range of several megawatts, for operation times no less than 1 minute, and continuous (1 hr) if possible. It was found that only two practical mechanisms are available for producing high-power direct current at low impedance levels. One method consists of using transformers for reducing the ordinary power line impedance to the desired level and then rectifiers and filters to provide the direct current. The other method was that of homopolar induction.

The transformer-rectifier system was discarded because of the high ripple level present in the output. Three homopolar motor-generator system designs were presented to the NASA for consideration, two using mechanical brushes for collecting the output current and one using the liquid-metal alloy sodium-potassium (NaK).

Analysis of the three systems resulted in the awarding of a contract to the Allis-Chalmers Manufacturing Company to produce a homopolar motor-generator set using liquid NaK for current collection. This decision was based on cost and maintenance considerations. This machine is now in operation at the Lewis Research Center.

DESCRIPTION

A photograph of the homopolar installation is shown in figure 1. The drive motor is off the picture to the right and is a 2500-horsepower three-phase induction motor which operates from a 2300-volt service main. The 1785-revolution-per-minute motor output is increased to 7200 revolutions per minute through a gear box which then drives the generator. The generator field is driven from a motor-generator exciter set. Figure 2 shows the operating range of the system up to the 1-minute limits. The continuous rating of the generator is 60,000 amperes at 1.8 megawatts, with an upper current limit of approximately 300,000 amperes and a power limit of about 4.5 megawatts. Experience has shown these values to be quite conservative. The time of operation at the maximum current level has not been determined as yet, but the 4.5-megawatt power level can be realized at a current of 250,000 amperes for a time of 30 seconds.

The output potential of a homopolar generator is a function of rotational speed and field power. Since for this particular system the speed is a constant 7200 revolutions per minute, the limit of 38 volts is set by the maximum ratings of the generator field windings and the maximum output of the exciter.

The output of the homopolar generator is controlled through control of the exciter set. There are two modes of operation available, called manual and automatic. In the manual mode of operation the exciter input is driven from an adjustable autotransformer and bridge rectifier. The autotransformer is driven by a push-button-controlled reversible motor, and thus the main generator output voltage can be raised or lowered at will by merely pressing the appropriate button. Since the generator internal resistance is only several microhms, the manual mode of operation provides a constant voltage or zero impedance characteristic, whereby the system current is determined only by the load resistance.

The automatic control system provides a potentiometer which preselects a desired load current. Depressing a button then causes the generator output to rise until the load current is at the preselected value. The automatic system then regulates the generator output to maintain the load current within a 1 percent band. This regulation is independent of load resistance and thus constitutes a constant current system (fig. 3).

Since the time constant of the generator field circuit is large (about 2.5 sec) compared with the desired rise time, the automatic control circuit uses a forcing technique to cause a faster rise in generator output. As a result, the output can reach 90 percent of the preselected value in about 1 second. The turn off characteristics are about the same as those for turn on. As can be expected, overshoot, undershoot, and instability can exist in such a system, and therefore damping circuitry is provided to eliminate any undesirable characteristics.

It is expected that the field-forcing mechanism will have much value in running large-volume high-inductance electromagnets which are limited in operating time.

A series of tests that were run to determine the characteristics of the system showed no detectable output ripple under any output condition. The search for ripple was made with an oscilloscope having a sensitivity of 1 millivolt per millimeter.

At present this generator is being used to power a helical water-cooled electromagnet capable of continuous operation at 100 kilogauss (figs. 4 and 5). The dimensional and operating parameters of this magnet are as follows:

Outer diameter, in.	16
Inner diameter, in.	2
Length, in.	9.7
Number of turns	~24
Turn thickness, in.	0.375
Turn spacing, in.	0.025
λ (space factor)	0.94
At 100 kilogauss	
Power, megawatt	1.46
Current, ka	86
Voltage, v	17
Water flow rate, (P = 60 psi) gal/sec	2.7

The low impedance level for which this magnet was designed allowed a self-supporting configuration (fig. 6) with only a very small amount of volume taken up by insulation material (about 0.3 percent). Coolant flow in the magnet is radially outward, entering the magnet case at the bottom and leaving by way of a chamber at the top. This arrangement allows the flow rate to be highest in the regions of large heat flux. One advantage of this design is the flattening of the radial temperature profile which would otherwise tend to be steep because of the reciprocal-radius current distribution.

To date, this magnet has been operated at measured field strengths up to 103.4 kilogauss and does not appear to be time limited in any way. Recent modifications, which have been made to improve the structural strength, should allow operation at slightly higher field values.

Under construction at present is a water-cooled 100-kilogauss magnet with a 4-inch inner diameter and a plasma containment mirror magnet facility which will be cryogenically cooled (by liquid neon). (See the paper presented at this conference by J. C. Laurence, G. V. Brown, J. Geist, and K. Zeitz entitled "A Large Liquid-Neon-Cooled Aluminum Magnet," J. 5.)

HOMOPOLAR GENERATOR INSTALLATION.
DRIVE MOTOR IS OFF PICTURE TO RIGHT

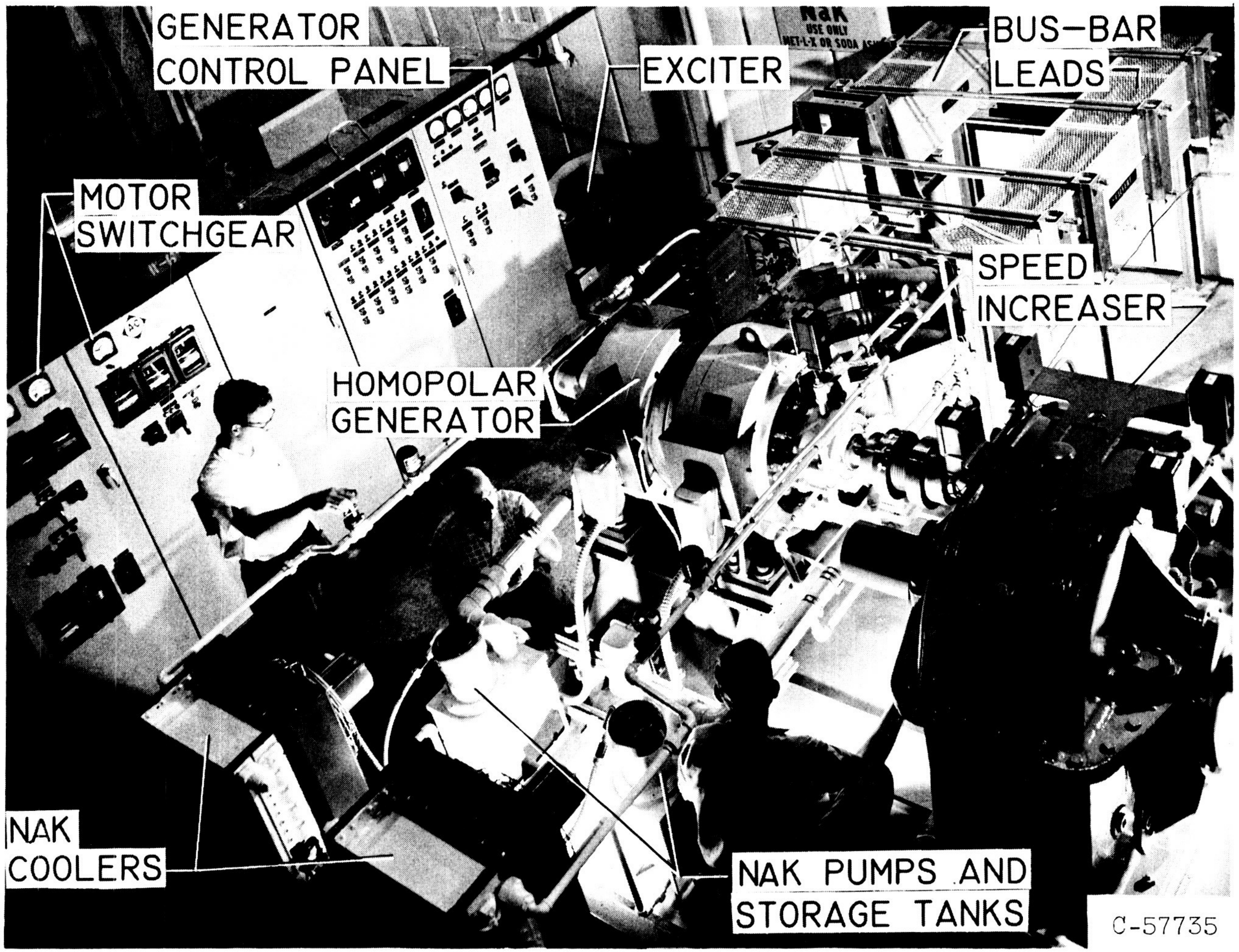

Fig. 1

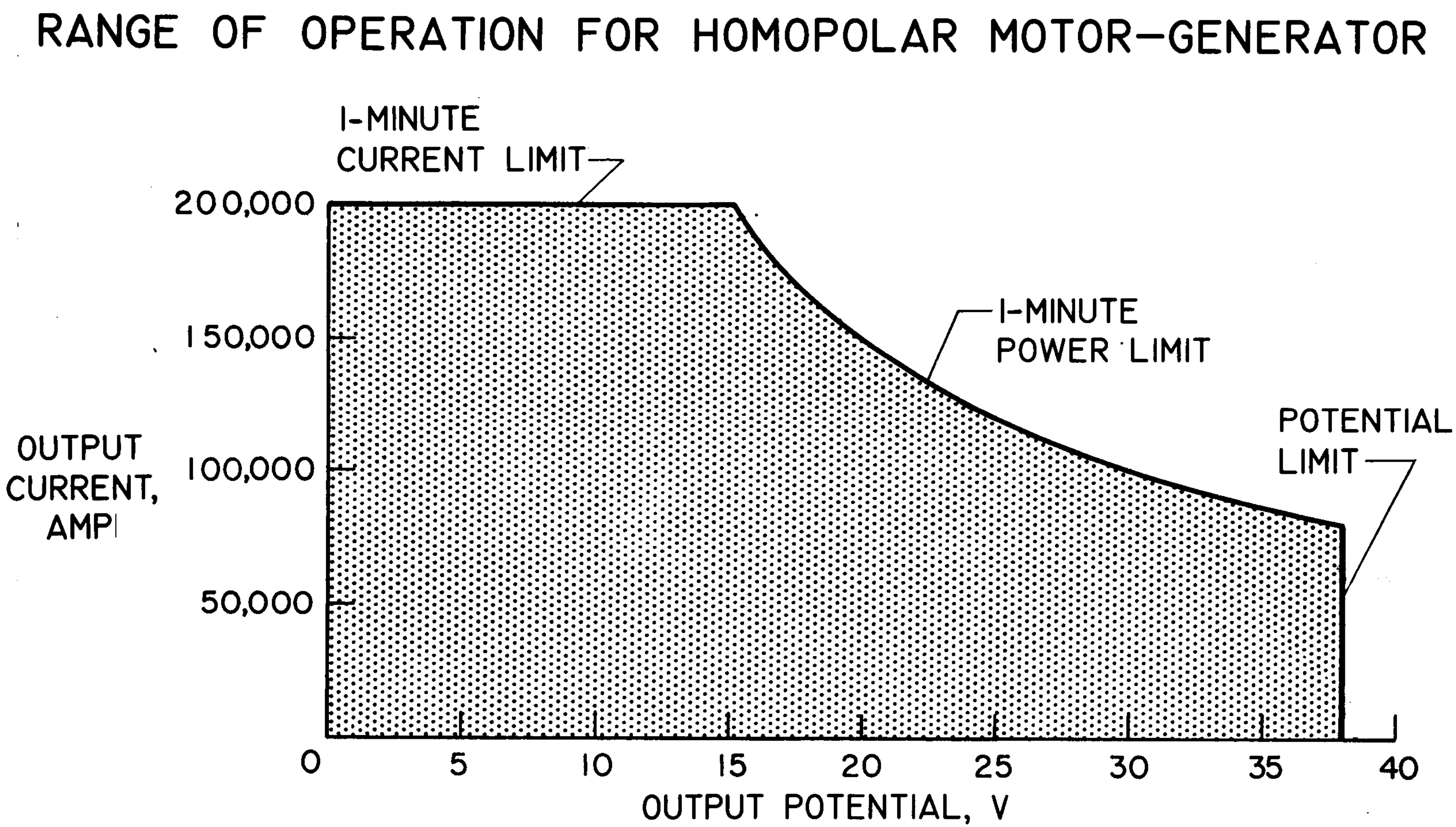
RANGE OF OPERATION FOR HOMOPOLAR MOTOR–GENERATOR
1-MINUTE
CURRENT LIMIT
1-MINUTE
POWER LIMIT
POTENTIAL
LIMIT
200,000
150,000
100,000
50,000
OUTPUT
CURRENT,
AMP
0
5
10
15
20
25
30
35
40
OUTPUT POTENTIAL, V

Fig. 2

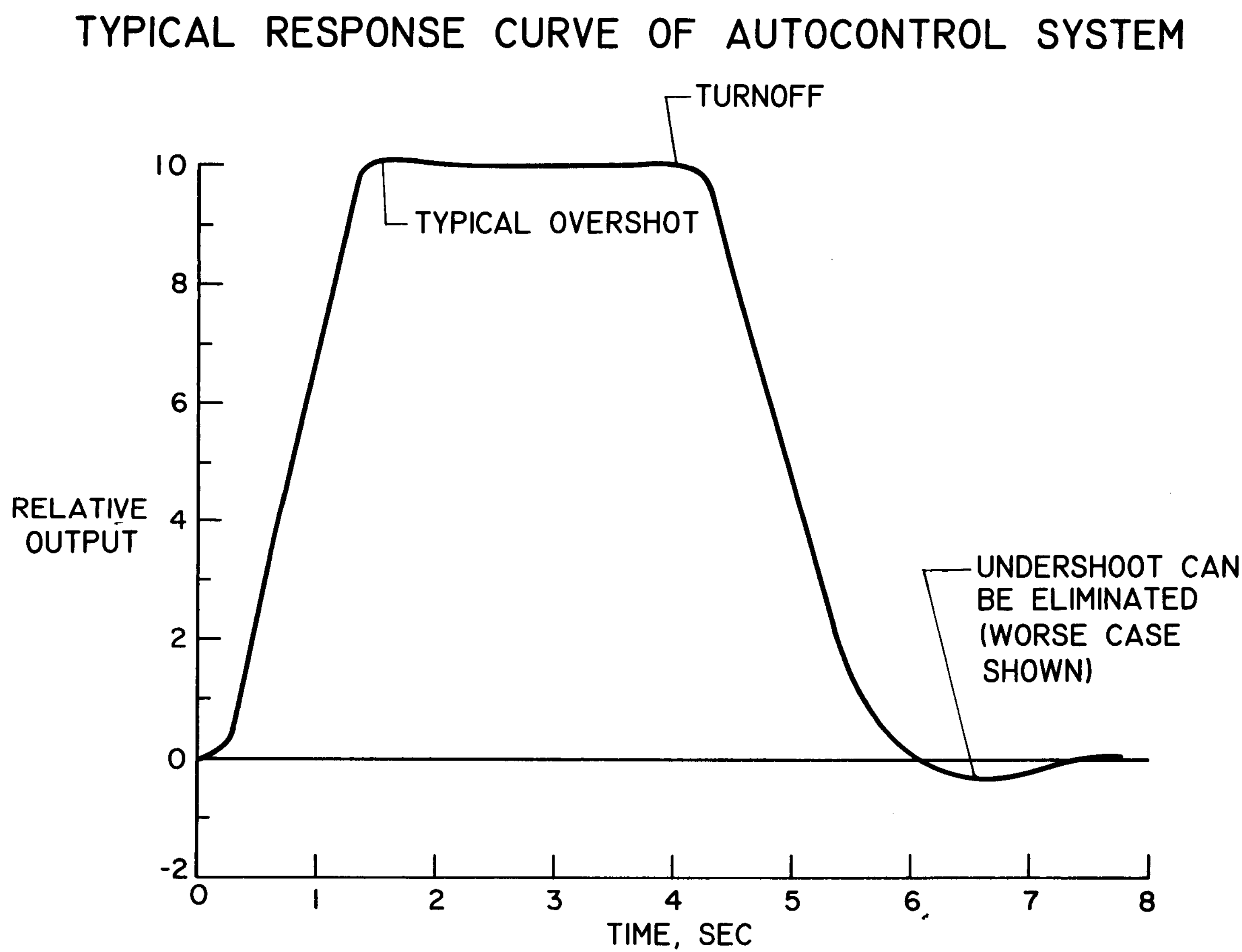
TYPICAL RESPONSE CURVE OF AUTOCONTROL SYSTEM
TURNOFF
TYPICAL OVERSHOT
UNDERSHOOT CAN BE ELIMINATED (WORSE CASE SHOWN)
RELATIVE OUTPUT
10
8
6
4
2
0
-2
0
1
2
3
4
5
6
7
8
TIME, SEC

Fig. 3

100 KILOGAUSS WATER-COOLED ELECTROMAGNET

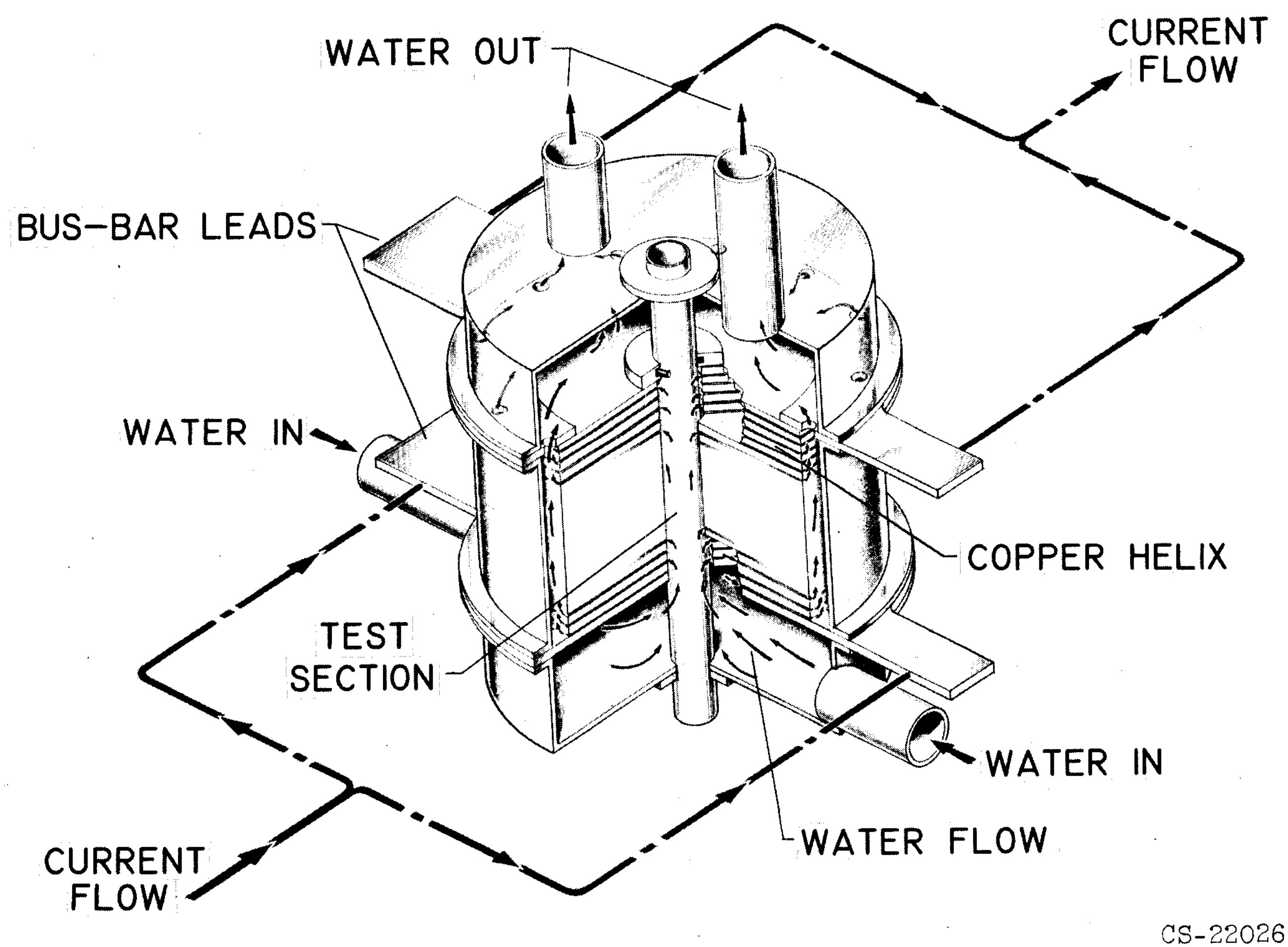

Fig. 4

100–KILOGAUSS WATER–COOLED ELECTROMAGNET INSTALLATION

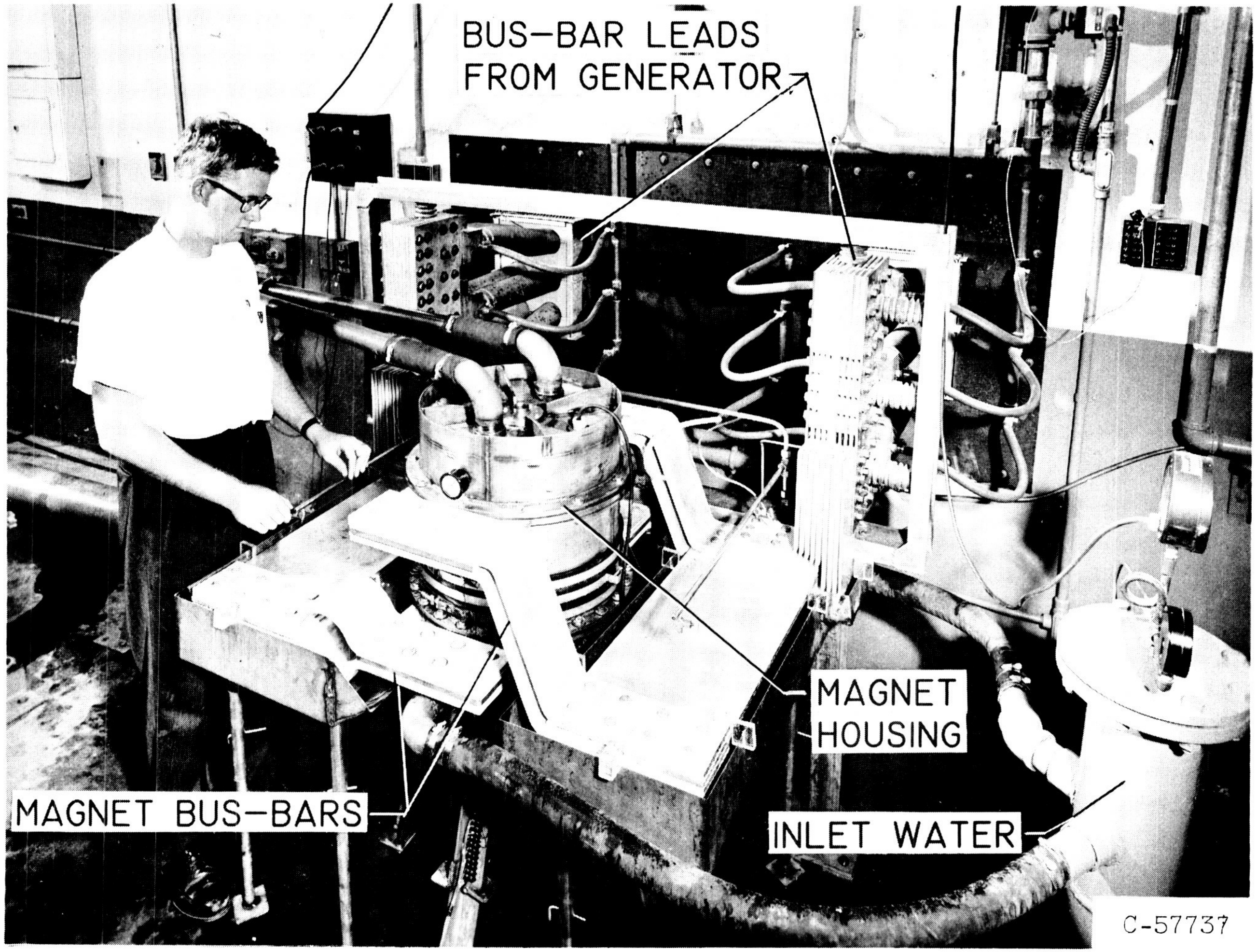

Fig. 5

ASSEMBLY OF SPACERS IN CORE OF 100-KILOGAUSS WATER-COOLED ELECTROMAGNET

C-56811

Fig. 6